SIGNATURE SIMULATOR

Background

This application claims priority under 35 U.S.C. §

119(e)(1) to co-pending U.S. Provisional Patent Application No.

5   60/428,205, filed November 20, 2002, and entitled "Methodology

to Synthesize Agent, Simulant, Interferent or Toxic Industrial

Chemical Signatures for an Interferometer-Based Spectral

Sensor", wherein such document is incorporated herein by

reference.

10   The U.S. Government may have certain rights in the present

invention.

The present invention relates to simulation and

particularly to simulation of scenarios for testing detectors

and related systems. More particularly, it relates to scenarios

15   that include simulated interferometer-based signatures of agent,

stimulant, interferent and toxic chemicals.

Testing of detectors or systems in real situations and

scenarios involving field measurements may often be very

expensive and quite hazardous. In lieu of the field

20   measurements, traditional simulations have been used. However,

they have been often inadequate for testing detectors, sensors

and related systems. Typically, traditional simulations have

been predicated on the principles of physics and do not

necessarily represent accurately the phenomenological behavior

needed for the testing the detectors, sensors, systems, and the like.

Summary

The present invention is an approach for constructing,

5   calculating and/or synthesizing agent, simulant, interferent, toxic or non-toxic chemical signatures to provide possible scenarios for testing an interferometer-based spectral sensor, detector, system, or the like. The simulations may address the artifacts and parameters specific to a distinct sensor, detector

10   or system. The present signature synthesis methodology may be different from that in the related art because of its relatively precise representation of sensor artifacts, sensor sampling error and sensor signal-to-noise ratio.

15   ## Brief Description of the Drawing

Figure 1 shows a block diagram of an algorithm design methodology;

Figure 2 shows the geometry of the two-slab cloud model for the agent/simulant/interferent simulation;

20   Figure 3 is a block diagram of a baseline simulation;

Figure 4 reveals the computational stages of the baseline simulation;

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Figure 5 is a top-level diagram of a detector chemical

agent simulation;

Figure 6 is a diagram of the preparation stage for the

simulation;

5   Figure 7 is a diagram of the calibration stage of the

simulation;

Figure 8 is a diagram of the restoration stage of the

simulation;

Figure 9 is a diagram of the major components of the

10   simulation software;

Figure 10 shows a profile of the values from a start scan

to an end scan in a simulation run;

Figure 11 high level operational flow diagram of the

simulation software; and

15   Figure 12 shows the removal of the original apodization

effect by dividing the truncated interferogram with a window.

Description

The invention may be an interferometer-based chemical agent

20   simulator which may synthesize agent, simulant, interferent

and/or toxic or non-toxic chemical signatures in background

interferograms. The signatures may be collected by an arbitrary

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interferometer sensor. Further, there may be simulated sensor outputs that have similar characteristics of a distinct, possibly non-existent sensor. The simulator may produce simulations to be integrated into an automated experiment

5   configuration and/or performance evaluation environment to test sensors, detectors, and related systems. One detector, sensor or system that may be tested is a Joint Services lightweight stand-off chemical agent detector (JSLSCAD). The JSLSCAD may be regarded as a state-of-the-art interferometer-based chemical

10   agent detector having baseline chemical agent detection algorithms. Although the present simulator may be used for testing many kinds of sensors, detectors and systems, the JSLSCAD may be considered as an example detector that may be provided simulated chemical agent signatures.

15   The simulator may be designed with algorithms to calculate and/or synthesize artificial interferometer-based signatures for a simulation of a scenario to be sensed. Figure 1 shows a block diagram of an algorithm design methodology. Field data 11 and atmospheric conditions 12 may be input into a ground truth tool

20   13. Ground truth tool 13 may allow the user to enter or establish the ground truth, e.g., types of background, and tool 13 may compute some basic features of the input, e.g., peak

amplitude, locations and kurtosis. (Kurtosis may be a quantity
indicative of a general form of a statistical frequency curve
near the mean of a distribution.) Selected data with ground
truth from tool 13 may go to a simulation block 14. Also input
5   to simulation block 14 may be agent absorption coefficients 15
and system performance requirements 16. Simulation 14 may add
chemical agent and/or common battle field signatures to
background data which cannot be obtained in field collection.
Simulation 14 may have training data 17 output and a sequestered
10   test data 18 output. Sequestered test data 18 may be input to
detection performance test and evaluation 19. Training data 17
may be input to algorithm 20. An output of algorithm 20 may go
to detection performance test and evaluation 19. Pd
(probability of detection) and Pfa (probability of false alarms)
15   signals may be an output of Detection performance test and
evaluation 19. This output may be fed to algorithm development
20. Detection performance test and evaluation 19 may test the
sensor or detector outputs (both field and simulated data) with
a suite of algorithms. It may also evaluate the performances
20   via a comparison with ground truth information 13. Algorithm
development 20 may design, code and train detection algorithm
candidates based on the sensor, agent/interferents and

background phenomenologies. Features of the algorithm design
methodology may include model based on first principle
phenomenology and a unified simulation, development/train, test
and performance evaluation package.

5   A baseline detector or sensor chemical agent simulation 25
may be designed for calculation of synthetic chemical agent
signatures utilizing background scene measurements obtained with
an arbitrary sensor 21 of Figure 2. A measurement may be
transformed into a synthetic representation of the sensor data
10   that would be obtained with a possibly distinct sensor,
utilizing chemical agent absorptivity coefficients,
specifications for the sensor's sample comb, the scene
configuration and the signal-to-noise ratio of sensor 21. The
baseline simulation configuration for signature synthesis is
15   shown in Figure 2 with radiance (N_{C1}) and transmission (τ_{C1}) of
the front cloud slab C1, radiance (N_{C2}) and transmission (τ_{C2}) of
the back cloud slab C2, the background of the scene with
radiance (N_B) and foreground (N_F, τ_F).

A block diagram of simulation 25 is shown in Figure 3. The
20   major components of simulation 25 may include sensor response
removal 24, spectral characteristics addition 27, atmospheric
attenuation 28, MODerate-resolution atmospheric TRANmittance and

radiance model (MODTRAN) 23, and sensor response addition 29.

MODTRAN is a FORTRAN-like computer code designed to determine or

model atmospheric transmission and radiance. MODTRAN was

developed principally by the U.S. Air Force Research

5   Laboratories. Simulation 25 may include sensor response removal

having inputs from field data 11 and sensor response 26, and an

output connected to an input of a spectral characteristics

addition 27.Agent absorption coefficients 15 may be connected to

another input of special characteristics addition 27. An output

10   of special characteristics addition 27 may be connected to an

input of atmospheric attenuation 28. MODTRAN 23 may have an

input from atmospheric conditions 12 and an output pertaining to

radiance and transmission of the atmosphere connected to another

input of atmospheric attenuation 28. An output from atmospheric

15   attenuation may be connected to an input of sensor response

addition 29. Sensor response 26 may be connected to another

input of sensor response addition 29. An output of sensor

response addition 29 may be simulated data.

      Sensor response removal 24 may remove the sensor induced

20   affects in the input signal and the output is sensor-independent

signature of the background. Spectral characteristic addition

27 may have the signatures of the agent and /or battlefield

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interferents added to the background only signature. The

signatures may be based on the concentration, temperature

difference, and field of view (FOV) coverage. Atmospheric

attenuation 28 may have the signature properly adjusted due to

5   the atmospheric transmission, based on the range of the agent

cloud and atmospheric conditions. Sensor response addition may

have the affects of the sensor response introduced into the

signature, creating the simulated data that the sensor should

output.

10   Features of simulation 25 may include a first principle

phenomenological model (spectral absorption/radiation) and

Government off the shelf (GOTS) proven atmospheric models may be

used relative to MODTRAN 23. Simulation 25 may be sensor

independent (i.e., may simulate signature of arbitrary Fourier

15   transform infrared (FTIR) spectrometers, including JSLSCAD)

Simulation 25 may have two agent/interferent clouds that allow

multiple agents and battlefield entries, which can be either

mixed or separated.

The computational stages of the baseline simulation 25 for

20   the detector are shown in figure 4. Parameters for each

spectrum 46 may be computed. From ground truth of tool 13 and

from case definition, specific parameters may be determined for

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each subfile. These parameters may include FOV coverage
parameters, MODTRAN 23 inputs, cloud slab (C1 and C2)
temperatures, components and their CLs. A calibrated background
spectrum 51 (N_B) may be obtained. Relative to an atmospheric

5   model 52 from conditions 12, a MODTRAN 23 input file may be
constructed. MODTRAN 23 may be run and the radiance N_F and
transmission τ_F arrays may be recovered. N_F and τ_F may be
convolved with a sinc function representing the Fourier
transform of the temporal averaging window corresponding to the

10 sample spacing of the interferometer to adjust resolution.
Also, N_F and τ_F may be interpolated to sample a comb of N_B.

A cloud model 53 involving N_{C1}, τ_{C1} and N_{C2} and τ_{C2} may be
determined. For each cloud slab (C1 and C2), an argument (ARG)
may be constructed for the components of the respective slab.

15
$$ARG_{C1} = \alpha_1 CL_1 + \alpha_2 CL_2 + \ldots + \alpha_n CL_n$$
$$ARG_{C2} = \alpha_1 CL_1 + \alpha_2 CL_2 + \ldots + \alpha_m CL_m$$

where α_i = absorptivity coefficient for component i as a function
of ν. Transmission terms $\tau_{C1} = \exp(-ARG_{C1})$ and $\tau_{C2} = \exp(-ARG_{C2})$
may be computed. Also computed may be radiance terms $N_{C1} =$

20 $N_{BB,C1}(1-\tau_{C1})$ and $N_{C2} = N_{BB,C2}(1-\tau_{C2})$ where $N_{BB,C}$ = Planck's function
for each slab at the temperature of the slab as a function of ν.

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A simulated spectrum 47 (N_{SIMUL}) may be built as indicated by the following equation.

$$N_{SIMUL} = S_1*(N_B-N_F)*\tau_{C1}*\tau_{C2}+S_1*N_{C2}*\tau_F*\tau_{C1}+S_2*(N_B-N_F)*\tau_{C2}+S_2*N_{C2}*\tau_F+S_1*N_{C1}*\tau_F+N_F \; ,$$

5   where S_1 = fraction of FOV coverage by cloud 1 and $S_2=1-S_1$. Then a signal-to-noise compensation 48 may be incorporated.

An alternate realization of the phenomenological synthesis calculation may be the following. If the sensor-based measurement is defined to be the background of the scene, then a

10   methodology may exist to estimate the signature that would be observed if the sensor was actually further away from the scene along the same view direction. The reference scene does not have to be compensated for the atmosphere between the sensor and the agent cloud because the agent cloud may be envisioned to be

15   located at the sensor location. The "virtual" sensor may be further away from the scene along the view direction of the sensor for the original sensor data. Then the equation designated "Build simulated spectrum" in Figure 4 may become

$$N_{SIMUL} = S_1*N_B*\tau_{C1}*\tau_{C2}*\tau_F+S_1*N_{C2}*\tau_F*\tau_{C1}+S_2*N_B*\tau_{C2}*\tau_F+$$

20    $$S_2*N_{C2}*\tau_F+S_1*N_{C1}*\tau_F+N_F \; ,$$

where

S_1 = fraction of FOV coverage by cloud 1 and

$s_2 = 1-s_1$

Figure 5 is a top-level diagram of the detector (e.g., JSLSCAD) chemical agent simulation. It shows inputs 31 (to simulation 25), preparation 32, calibration 33, simulation 25 and restoration 35. Inputs 31 to simulation 25 may include a background interferogram and ground truth, ambient and liquid nitrogen blackbody interferograms and ground truth, absorptivity data and a case definition of the simulation. Preparation 32 may include preprocessing 36, data conversion 37, normalization 38 and fast Fourier transform (FFT) 39. Calibration 33 may include compute ambient blackbody spectrum 41, compute theoretical ambient blackbody spectrum 42, compute theoretical LN_2 spectrum 43, compute response correction array 44 and compute calibrated spectrum 45. Simulation 25 may include compute parameters for each spectrum 46, build simulated spectrum 47 and signal-to-noise compensation 48. Build simulated spectrum 47 may have inputs background spectrum 51 (calibrated N_B), atmospheric model 52 (N_F, τ_F), and cloud model 53 (N_{C1}, τ_{C1}, N_{C2}, τ_{C2}). Restoration 35 may include uncalibrate 56, inverse fast Fourier transform (IFFT) 57 and output to database 58. Figure 4 is a simulation stage 25 block diagram.

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Figure 6 is a preparation stage 32 block diagram.
Preprocessing 36 may select a set of subfiles upon which to
simulate agent/interferent signatures (allowing for co-adding,
if desired) and perform co-adding, if desired, to yield a

5   contiguous set of subfiles to utilize. Data conversion 37 may
transform measured interferogram signatures to sample spacing of
a new interferogram sensor. Normalization 38 may normalize for
sensor gain and, if co-adding is performed, the data should be
normalized (i.e., data points/# of co-adds per resultant

10   subfile). FFT 39 (I_B) may compensate sensor measurement for
sensor self radiance (pointwise subtraction of a liquid nitrogen
calibration interferogram from a measured interferogram),
triangular apodization (i.e. a tapering function), zero pad to
4096, FFT and phase correct and preserve reference phase for

15   restoration process.

Figure 7 is a calibration stage 33 block diagram. Compute
ambient blackbody spectrum 41 (I_A) may include a pointwise
average of subfiles 1-128 from calibration file and a
compensation for sensor self radiance, triangular apodization,

20   FFT and phase correct. Compute theoretical ambient blackbody
spectrum 42 ($N_{BB,A}$) may be at $T = T_{AMBIENT} + 273.15$ degrees Kelvin,
calculated from a Planck function for an I_A sample comb. Compute

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theoretical LN_2 spectrum 43 ($N_{BB,L}$) may be at T = 77 degrees

Kelvin, calculated from a Planck function for an I_A sample comb.

Compute response correction array 44 (R) where R may be

calculated as $I_A/(N_{BB,A}-N_{BB,L})$. Compute calibrated spectrum 45 (N_B)

5 where N_B may be calculated as I_B/R.

Figure 8 is a restoration stage 35 block diagram.

Uncalibrate 56 (I_{SIMUL}) where I_{SIMUL} may be calculated as $N_{SIMUL}*R$.

IFFT 57 may subtract the original background spectrum, use a

stored reference phase from FFT to reapply phase, IFFT, remove

10 the apodization originally applied, reintroduce sensor self-

radiation and unnormalize for gain. Output to database 58 may

output simulation results to a database properly annotated with

simulation ground truth parameters.

There may be simulation software that adds the chemical

15 agents and/or common battlefield inferents into background

interferograms. Simulation software may synthesize agent,

simulant and/or inferent signatures in background interferograms

which may be collected by a sensor. The outputs may be sensor

specific and expected to have similar characteristics of the

20 anticipated sensor. The simulation may address many artifacts

and parameters specific to the sensor. A simulation that may

apply to a different sensor would require modification to the

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simulation software. The terms "scan" and "interferogram" may be used interchangeably. A scan or interferogram may mean a 2048 point data sequence that is or simulates the sensor output. Each data point of the sequence may be represented by a 16 bit

5   word.

The assumptions and requirements needed to complete the simulation software may include a local, executable MODTRAN (version 3.7) which can be invoked by the simulation software, an executable MATLAB® (version 5.2) and its signal processing

10 toolbox which can be invoked by the simulation software. MATLAB® (Matlab) may be used as a numerical computing tool. The background interferograms used for simulation may be already imported in chemical agent detection software environment (CADSE) database. Also, these interferograms may be already

15 converted to have the same attributes as the JSLSCAD, e.g., 4 wavenumber resolution and 2048 points. The ancillary information associated with the interferograms (e.g., ambient blackbody and liquid nitrogen references) may be also correctly stored in the CADSE database. The absorption coefficients of

20 the agent and interferents may be stored in a file whose format, resolution, and number of points are specified.

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The simulation software may be partitioned into three major

components: CADSE simulation 61, Matlab simulation 62 and

MODTRAN 23. A user interface 63 may be part of CADSE simulation

61. Figure 9 shows the connections between the components.

5   User interface 63 may have a two-way connection with CADSE

simulation 61. CADSE simulation 61 may have input connections

from atmospheric transmittance and radiance 65, background

measurement experiment or environment (BME) interferogram 66 and

ancillary information 67. CADSE simulation 61 may also have

10 two-connections with MODTRAN 23 and Matlab simulation 62. CADSE

simulation 61 may have output connections to simulated

interferogram 64 and cards 68. MODTRAN 23 may have an input

connection from cards 68 and an output connection to atmospheric

transmittance and radiance 65. Atmospheric transmittance and

15 radiance 65 may be the atmospheric information from MODTRAN 23

to CADSE simulation 61.

CADSE simulation 61 may be the coordinator that obtains the

necessary information from the user via user interface 63, gets

BME background interferogram 66 and associated or ancillary

20 information 67 from the CADSE database, creates the protocols to

MODTRAN 23 and Matlab 62, and saves simulated interferograms 64

and their ground truth information into the CADSE database.

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MODTRAN 23 may be the software for standard atmospheric

transmission and radiance 65 model. MODTRAN 23 may be used to

produce foreground atmospheric transmission and radiance.

Matlab simulation 62 may generate the simulated

5   interferograms 64 based on a two-slab cloud model. All of the

mathematical computations may be performed in Matlab simulation

module 62. However, the simulation software may run using

Matlab or C. The simulation software may require numerous

inputs, which can be grouped into three categories: MODTRAN 23

10 related, background interferogram related, and cloud slab

related. All the input values for a simulation run may be saved

and recalled for future reference.

The following items pertain to MODTRAN 23 related

parameters. Sets of eight cards 68 (i.e. input files in card

15 format) may be utilized for providing required inputs to the

MODTRAN 23 model. The values of most parameters may be fixed

for this application. Values of some parameters may vary

depending on the scenario, which the user may input via

interface 63. Alternative values may indicate options that are

20 related to different background and simulation scenarios. CADSE

simulation 61 may develop the sets of cards 68 based on the user

inputs and the above-noted fixed parameter values. These sets

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of cards 68 may be saved as a file that is input to the MODTRAN

23 executable.

The background interferogram related parameters may be a

category of inputs that relate to the background interferograms

5   66 in which agent and/or interferent signatures are to be added.

Some inputs may specify the background interferograms 66, and

some inputs may relate to the background interferograms 66, such

as the calibration references. The majority of these inputs may

be retrieved from the CADSE database once they are specified.

10 The list of inputs, their format and descriptions are tabulated

in Table 1.

Table 1: Input parameters related to the input interferograms 66

Name	Format	Value/ source	Description
Scan set	CADSE UI		The scan set specifies the set of interferograms in which agent/interferents will be simulated upon.
Ambient Blackbody Reference		Calibration file referred in global file header	Each file that a selected scan originated from is associated with a calibration file. The calibration file consists of three sets of references: an ambient blackbody set, a polystyrene reference, and a LN_2 reference set. The ambient blackbody set that corresponds to the selected scan is needed.
LN_2 Reference		Ditto	This is the LN_2 reference set as stated above
Slant angle		Subfile header	The slant angle of the scan. Noted that the angle required for MODTRAN is Zenith angle, not the elevation angle as in the subfile header.
Gain		Global header	The gain of the sensor.
Ambient temperature		Global header	The ambient temperature when the scan was collected.
Barometric		Global	The barometric pressure when the scan was collected.

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Pressure		header	
Relative humidity		Global header	The percentage of relative humidity when the scan was collected.
numCoadd		User	Number of interferograms coadded

A byproduct of the input information may be the number of scans (subfiles) which the agent and interferents will be simulated upon. This number may be referred as numScan throughout this document.

The following pertains to cloud slab related parameters. Two cloud slabs may be simulated in the model. Further, the model may allow multiple components in each cloud slab. Here, the maximum number of components may be four, even though the number may other than four. The model also may assume that the back slab has 100 percent FOV coverage, and that the front slab may have 0 to 100 percent FOV coverage. To describe the clouds of agent/interferents, following inputs listed in Table 2 may be considered to be required.

Table 2: Input parameters related to the cloud slab

Name	Description
Range	Distance profile from the clouds to the sensor (km). The two clouds are assumed to have the same distance.
Coverage	The field of view coverage profile of the front cloud slab (C1) in the form of a fraction from 0 to 1.
T_{c1}	The temperature profile of the front cloud, C1
NumCompC1	Number of components in the front cloud
$CompID_{1,c1}$	The ID tag for the first component in C1
$CL_{comp1,c1}$	The CL profile for the first component in C1

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...	The ID tag and CL profile for the ith component in C1
$CompID_{numComp1,c1}$	The ID tag for the last component in C1
$CL_{numComp1,c1}$	The CL profile for the last component in C1
T_{c2}	The temperature profile of the back cloud, C2
NumCompC2	Number of components in the back cloud
$CompID_{1,c2}$	The ID tag for the first component in C2
$CL_{comp1,c2}$	The CL profile for the first component in C2
...	The ID tag and CL profile for the ith component in C2
$CompID_{numComp1,c2}$	The ID tag for the last component in C2
$CL_{numComp1,c2}$	The CL profile for the last component in C2

The profile as stated in Table 2 may denote the values from the starting scan to the ending scan in the simulation run (experiment). The profile, which is shown in Figure 10, may be captured with 4 numbers: startValue 71, endValue 72, breakPoint1 73, and breakPoint2 74. StartValue 71 does not need to be smaller than endValue 72, and the breakpoint1 73 may be less than or equal to breakPoint2 74. Breakpoints1 73 and breakpoint2 74 may be expressed in percentage. Numerous forms of profiles, such as constant, linearly increasing, linearly decreasing and so forth may be specified with these four parameters. Figure 10 shows a profile 75 that may specify the values from the start scan to ending scan.

Another input related to the cloud slabs is the absorption coefficients file 15, which may store the absorption coefficients of all the agents, simulants and interferents. The

format of absorption coefficient file 15 may be defined as having an open-ended data file, fixed-length records; one agent per record, and vice versa; and an agent "name" in user interface 63 linked to stored index/key.

5   A given record may contain four elements: Cstring - AgentName; DWORD - IndexKey; CString - Comment; and float - AgentCoefficient[2184]. AgentName may be a unique, recognizable identifier, 2 -> 16 characters in length. IndexKey (also unique) may be transparent to the user, and assigned at the

10   start of the respective record. Comment may be optional, variable (or limited) length. AgentCoefficient array may consist of 2184 floating point values. Upon retrieval, these may be converted to mg/m2 by multiplying stored value * 0.0001. A starting wavenumber (each 1st data point) may be 388.17558 cm^{-1}

15   and a step may be 0.96716738 cm^{-1}. For reference, the ending wavenumber thus may calculate out to something like 2499.50197 cm^{-1}.

         As to outputs of the simulation software, most of them may be stored back into the CADSE database. These outputs may

20   include simulated interferograms 64 as scan representations in the CADSE database. These scans may be associated with a new global file header and subfile information. Another output may

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be a new global file header. Since the contents of the scans

(subfiles) may change, it could be beneficial to have a new

global file header associated with the simulated data. In

particular, the following information in the global file header

5   may be changed. A filename may change from D****** to

S******, where D stands for data and S stands for simulation.

The rest of the character sequence in the file name may be the

same. One may note also that the same interferogram could be

used multiple times to simulate different

10   agents/simulants/interferents, yielding many interferograms.

Thus, the association of the synthesized data with a global

header may take into account this situation. Another output may

be subfile information originally associated with simulated

interferograms 64. An output may also be simulation ground

15   truth information associated with each of the simulated

interferograms 64, i.e., components in the two cloud slabs

(their spectral ID, temperature, CL, range, FOV coverage).

Other outputs that are not stored in the CADSE database may

include all user inputs to the simulation which need to be

20   stored in a file with unique name.

A high level operational flow diagram of the simulation

software is shown in Figure 11. A user interface and data

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retrieval block 81 may have an output connected to an input of a

MODTRAN atmospheric simulation block 82, a sensor self radiation

and response block 83 and a cloud radiance and transmittance

block 84, respectively. Another output of user interface and

5   data retrieval block 81 may go to an input of a synthesis block

85. An output of MODTRAN atmospheric simulation block 82 may go

to an input of synthesis block 85. An output of sensor self

radiation and response block 83 may go to an input of synthesis

block 85. An output of cloud radiance and transmittance block

10   84 may go to an input of synthesis block 85. An output of

synthesis block 85 may go to an input of a data storage block

86. Sensor self radiation and response block 83, cloud radiance

and transmittance block 84 and synthesis block 85 may be

contained in a Matlab module 87.

15   User interface and data retrieval block 81 may provide a

user an interface such that the user can input the parameter

values. The user interface may be in a form of a sequence of

windows. Based on the input values, this block 81 may then

retrieve and compute all of the required data for the

20   simulation, e.g., the ambient blackbody, and liquid nitrogen

references. Four categories of outputs defined for this block

81 may include an input file to MODTRAN block 82, inputs to

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sensor response/self radiation computation block 83, inputs to

cloud radiance and transmission computation block 83, and inputs

to synthesis block 85.

MODTRAN simulation block 82 may compute the foreground

5   atmospheric radiance and transmission. Input to block 82 may be

in a form of an input file. Outputs of block 82 may also in the

form of files. Decimation of the MODTRAN outputs to match the

simulated resolution may be required.

Sensor response and self radiation block 83 may compute the

10   sensor self radiation and the sensor response, which may be used

for calibration and uncalibration. Calibration may remove the

sensor characteristics and artifacts before the

agent/interferent spectral characteristics are added.

Uncalibration, then, may add back the sensor characteristics and

15   artifacts to the simulated spectrum. Computing the sensor self-

radiation and the sensor response may require ambient black body

reference interferograms, liquid nitrogen (LN_2) reference

interferograms, and ambient temperature. The interferogram to

spectrum transformation may be a commonly used function that

20   involves some computations. The outputs of this transformation

may be the phase corrected spectrum and the phase array.

Likewise, the inverse transformation of a spectrum to an

23

interferogram may be another commonly used function. The output

of this transformation may be the interferogram.

Cloud radiance and transmission block 84 may compute the

transmission and radiance of the two cloud slabs based on their

5   temperatures, their components' absorption coefficients, and

CLs. The computations for each of the cloud slabs may include

computing the exponent of the transmission based on the

components and their absorption coefficients (ARG as described

in the simulation model), computing the transmission from the

10   exponent, computing the radiance from the transmission and

theoretical black body at the cloud temperature, and resampling

the transmissivity and radiance to the synthesized signature's

sample comb. The spectral range of interest may be from 700 cm^{-1}

to 1450 cm^{-1}. However, the simulation may need to extend this

15   range further to cover any filter window, and ensure that

discontinuity, which causes undesirable disturbance in the final

signal, is avoided.

Synthesis block 85 may synthesize the agent/interferent

into the input interferogram. Computations may include coadding

20   (average) the number of interferograms based on the numCoadd

input value, subtracting averaged liquid nitrogen interferogram

from the averaged interferogram, transforming the difference

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interferogram to a background spectrum (I_{B-L}), computing the calibrated spectrum, or the scene radiance (N_B), synthesizing the simulated spectrum (N_{SIMUL}), computing the sensed simulated spectrum (I_{SIMUL}), adding appropriate noise to the simulated

5   spectrum(I'_{SIMUL}), computing the inverse transformation to obtain the synthesized interferogram, and adding averaged liquid nitrogen interferogram in order to negate the effects of normalization for the simulated interferogram.

Data Storage block 86 may store the results into the CADSE

10   database and to the output file. Modifications of appropriate attributes and creation of new attributes in the database may be necessary. Interface between the Matlab and the CADSE simulation module may be specified in the following. CADSE may invoke the Matlab function and pass the corresponding arguments.

15   The Matlab function may be called Main_Simulation as described below:

```
function [jslscad_interferogram] = Main_Simulation( subfiles, sf_specs, sf_A, sf_L,
                                     sf_calib_file_specs, configuration_specs,
                                     absorptivity_coefficients, N_F, tau_F, step_size, ilsf,
20                                   half_width)
```

where
     Inputs may include:

subfiles	(NPTS x nscan) matrix for storage of background interferogram
25 sf_specs	nScan x 3 matrix for storage of sensor gains (col 1), centerburst (col 2),calibration file offset(col 3)

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sf_A	NPTS x nCalibration matrix for storage of ambient blackbody calibration interferograms
sf_L	NPTS x nCalibration matrix for storage of liquid nitrogen calibration interferograms
sf_calib_file_specs	nCalibration x 5 matrix for storage of sensor gains for ambient blackbody calibration interferograms, centerburst locations for ambient BB calibration interferograms, sensor gains for liquid nitrogen calibration interferograms and centerburst locations for liquid nitrogen calibration interferograms respectively
configuration_specs	nscan x 23 matrix for storage of the configuration specifications per definition shown in TABLE specs below.
absorptivity_coefficients	nr1 x nAgent matrix for storage of agent absorptivity coefficients
N_F	nr1 x nScan matrix for storage of atmospheric spectral radiance
tau_F	nr1 x nScan matrix for storage of atmospheric spectral transmissivities
step_size	interferogram stepsize [micrometers]
ilsf	instrument line shape function
half_width	half width of time domain weighting function for calculation of reference spectrum.

Outputs may include:

jslscad_interferogram	NPTS x nScan array for storage of synthetic interferogram

The number of points per interferogram, NPTS, may be defined internally.

TABLE specs may include:

Matrix Column	Definition
1	Ambient Temperature
2	Spectral Resolution
3	FOV coverage
4	Cloud Slab #1 - temperature
5	Cloud Slab #1 - number of components
6	Cloud Slab #1 - component 1 absorptivity coefficients offset
7	Cloud Slab #1 - component 2 absorptivity coefficients offset
8	Cloud Slab #1 - component 3 absorptivity coefficients offset
9	Cloud Slab #1 - component 4 absorptivity coefficients offset
10	Cloud Slab #1 - component 1 CL
11	Cloud Slab #1 - component 2 CL
12	Cloud Slab #1 - component 3 CL
13	Cloud Slab #1 - component 4 CL
14	Cloud Slab #2 - temperature
15	Cloud Slab #2 - number of components

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16	Cloud Slab #2 - component 1 absorptivity coefficients offset
17	Cloud Slab #2 - component 2 absorptivity coefficients offset
18	Cloud Slab #2 - component 3 absorptivity coefficients offset
19	Cloud Slab #2 - component 4 absorptivity coefficients offset
20	Cloud Slab #2 - component 1 CL
21	Cloud Slab #2 - component 2 CL
22	Cloud Slab #2 - component 3 CL
23	Cloud Slab #2 - component 4 CL

A two-slab cloud model may be used in the agent/interferent simulation software. Figure 2 shows the geometry of the two-slab cloud model for the agent/simulant/interferent simulation. The simulation may model the sensed radiance as the cumulative effects of the background radiance, the radiance and transmission of clouds 91 and 92 (C1 and C2) and that of the foreground. Thus, the four components (i.e., background, Cloud 91 (C1), cloud 92 (C2), and foreground) of the model may have their own radiance, $N_{B'}$, N_{C1}, N_{C2}, and N_F, respectively. The two cloud slabs and the foreground may have their own transmission, τ_{C1}, τ_{C2}, and τ_F, respectively. The two cloud slabs may be assumed to be at the same distance from sensor 21. Each cloud (91, 92) may be composed of a homogeneous mixture of chemical components at a specific temperature. The simulation may allow a maximum of four components in each cloud slab. Each component may be represented by a set of absorption coefficients at a specific concentration x path length (CL). In addition, the back cloud,

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C2, may be assumed to have a 100 percent field of view (FOV) coverage but the front cloud, C1, may have a 0 to 100 percent FOV coverage. A shadow factor, s_1, which has a value of 0 to 1, may be defined as the fraction of cloud 91 (C1) covering cloud 92 (C2) within the FOV coverage. Thus, $s_1 = 1$ may imply that both clouds 91 and 92 are within the FOV, and $s_1 = 0$ may imply that cloud 91 (C1) is outside of the FOV. For convenience, another term, s_2, may be defined as $1 - s_1$.

The model may implicitly simulate one cloud slab. Several methods may be used to accomplish this. Setting $s_1 = 0$ is one way; setting the number of components in one of the clouds to be zero is another way. This model may assume that sensor 21 measured the sensed signal (interferogram) without the two clouds, I_B. The sensed interferogram, I_B, may be converted to radiance without the cloud, N_B. One may assume that $N_B = \tau_F N_B + N_F$. Then the simulated radiance, N_{SIMUL}, entering the sensor may be

$$N_{SIMUL} = s_1 (N_B - N_F) \tau_{C1} \tau_{C2} + s_2 (N_B - N_F) \tau_{C2} + N_F + s_1 N_{C2} \tau_{C1} \tau_F + s_2 N_{C2} \tau_F + s_1 N_{C1} \tau_F \cdots.$$

This simulated radiance may passes through sensor 21, which may detect the radiance and output the simulated sensed radiance, I_{SIMUL} as

$$I'_{SIMUL} = N_{SIMUL} * R$$

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This equation does not take into account the artificial

attenuation of the noise originally in the measured background

spectrum. (The noise compensation may take place in the raw

spectrum after the simulated radiance spectrum has been

5   uncorrected for sensor spectral response.) One may note that

$$I_{SIMUL} = I'_{SIMUL} + N_{noise}.$$

For now, the noise spectrum, N_{noise}, may be assumed to be 0,

because the noise is not estimated accurately. A more

definitive method to capture or compute the noise may be needed.

10 I_{SIMUL} may be in the spectral domain. Following computations of a

method 1 may transform I_{SIMUL} to an interferogram: 1) Restore

phase from the reference phase (computed in the forward

transformation); 2) Normalize the phase compensated measurement

data plus agent spectrum by the phase compensated measurement

15 data spectrum, I_B; 3) Perform inverse FFT; 4) Truncate the

transformed interferogram to half its length (assume zero-filled

before); 5) Remove original apodization effect by dividing the

truncated interferogram with a window shown in Figure 12 (δ is

the maximum peak location 93 in the figure); 6) Combine the gain

20 compensated measurement data interferogram with the unapodized

difference scaled by a factor of 2.0; and 7) Un-normalize with

original gain.

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Following may provide all the equations for computing the

terms in the above equations. s_1 is the shadow factor, which may

be the fraction of cloud C1 covering cloud C2 within the FOV.

Thus, s_2 may equal 1 - s_1.

5   R may be a response of the sensor and is computed as:

$$R = \frac{I_{A-L}}{N_{BB}^{A} - N_{BB}^{L}}$$

where

N_{BB}^{A} = the theoretical black body at ambient temperature,

and

10   N_{BB}^{L} = the theoretical black body at the temperature of

liquid nitrogen (77° K).

The theoretical black body may be computed using Planck's

function with

N_{BB}^{T} = $c_1 \times \bar{v}^3$ / (e $^{c2\bar{v}/T}$ - 1)   w/cm²/cm⁻¹/st ,

15   where

c_1 = 1.19089 × 10^{-12} w cm² sr⁻¹,

c_2 = 1.4388   cm · °K,

$\bar{v}$ = wavenumber value (cm⁻¹),

T = temperature (°K), and

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N_B = total radiance of the background and foreground,

(without the cloud slabs).

N_B may be computed from calibrating the spectrum, I_{B-L}, which is the measured background signal with the sensor self radiation

5   removed, as

$$N_B = \frac{I_{B-L}}{R}$$

I_{B-L} and I_{A-L} may be computed from the background (B) and the averaged ambient blackbody (A) interferograms (referred to as the input interferogram below) respectively. They may be

10   computed with a method 2 as follows: 1) Normalize the input interferogram for gain; 2) Subtract the normalized averaged liquid nitrogen interferogram from the normalized input interferogram; 3) Apodize the difference interferogram using a triangular apodization function, which has a value of 0.5 at the

15   center burst location (location of zero phase reference) and 0 values at the extended points 0 and Npts+1; 4) Zero-fill the apodized interferogram to double the length; 5) Apply FFT to the zero-filled interferogram; and 6) Phase correct the resulting spectrum with the generalized version of the Mertz method that

20   accounts for both magnitude and phase.

One may note the following term definitions.

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N_F, τ_F = the radiance and transmission of the foreground;

N_{C1}, τ_{C1} = the radiance and transmission of the front cloud

slab, C1; and

N_{C2}, τ_{C2} = the radiance and transmission of the back cloud

5   slab, C2.

The terms may be computed as

$$\tau_{c1} = e^{-ARG_{C1}} \quad \text{and} \quad \tau_{C2} = e^{-ARG_{C2}} \quad ,$$

$$N_{C1} = N_{BB}^{C1}(1 - \tau_{C1}) \quad \text{and} \quad N_{C2} = N_{BB}^{C2}(1 - \tau_{C2}) \quad ,$$

where

10   $$ARG_{C_1} = \alpha_1 CL_1 + \alpha_2 CL_2 + \ldots + \alpha_n CL_n \quad ,$$

$$ARG_{C2} = \alpha_1 CL_1 + \alpha_2 CL_2 + \ldots + \alpha_m CL_m \quad ,$$

α_i = absorption coefficient for component i as a function of

$\bar{\upsilon}$,

and

15   N_{BB}^{Ci} = The theoretical blackbody at the temperature of cloud

i, for i = 1,2.

The following function, f(x), may be used in the decimation

process -- that is to convolve it with a high resolution sampled

sequence, followed by an interpolation and subsample. The

20   resulting sequence may have a lower resolution.

The convolution function may be

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$$f(x) = \text{sin} c^2 x = \frac{\sin^2 x}{x^2}$$ (for triangular apodization), and

x = 0.88 $\pi \bar{\upsilon}$ / fwhm,

where

$\bar{\upsilon}$ = displacement from center of function (cm^{-1}), and

5   fwhm = full width at half maximum.

For JSLSCAD-like data, one may use a 33 point function,

normalized to unit area. If the high resolution sample interval

is 1.84451968, and the laser diode frequency is 0.662, then

$\bar{\upsilon}$ = 1.84451968 × INDEX (from center of function) cm^{-1}, and

10   fwhm = 3.2.

It may be noted that the above discussion is in the

spectral domain. The input to the simulation may be an

interferogram. Thus, the simulation may first transform the

input from the time domain to the spectral domain. Then the

15   agent and interferent synthesis as outlined may be performed.

Afterwards, the inverse transformation may convert the

synthesized spectrum back to the simulated interferogram.

Although the invention has been described with respect to

at least one illustrative embodiment, many variations and

20   modifications will become apparent to those skilled in the art

upon reading the present specification. It is therefore the

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intention that the appended claims be interpreted as broadly as possible in view of the prior art to include all such variations and modifications.